MINISTRY OF THE ENVIRONMENT
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ONTARIO

THE USE OF

PLASTIC PIPE

AS

BURIED GRAVITY-FLOW SEWERS

RESEARCH BRANCH

August, 1972

R. P. W2036

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August, 1972

Research Branch

Paper No. W2036

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ABSTRACT

A review of the development of flexible conduit design is given.

It is concluded that plastic pipe is acceptable for use as buried, gravity-flow sewers, subject to some restriction. In the absence of conclusive evidence of local conditions to the contrary, conservative design parameters should be used.

Provision should be made to obtain more useable design criteria as part of the testing and certification of plastic pipe.

THE USE OF PLASTIC PIPE AS BURIED GRAVITY-FLOW SEWERS

1.0 Introduction

"Plastic" pipe is a general term used to describe conduit manufactured of a variety of materials, but for the purpose of this report the term "plastic" will be limited to polyethylene (PE), acrylonitrile-butadiene-styrene (ABS), rubber modified styrene (RMS) and polyvinyl chloride (PVC).

This report has been requested by the Ministry in response to queries regarding the use of such plastic pipe for "building sewers" and "building drains" as defined by Canadian Standards Association Standard B182.1 - 1967, and therefore shall include, but not be limited to, such use.

The commercial production of plastic pipe was initiated in Europe in 1930, and in North America in 1948. Volume production was achieved in 1948 when PE pipe was introduced. In 1959, one hundred and sixty-one companies in the United States were manufacturing plastic pipe out of seventeen types of material approved by nationally recognized testing laboratories.

Plastic pipe has been widely accepted, particularly by Industry, for pressure pipe and exposed gravity-flow sewer applications but there has been some reluctance on the part of municipal officials and regulatory agencies to accept plastic pipe for below ground, buried, gravity-flow conditions. It is this aspect of plastic pipe use that is examined in this report.

Plastic pipe has some notable advantages when used as gravity-flow conduit. It is a smooth material and therefore has a low head-loss due to friction, (Hazen-Williams C = 150); it is supplied in long lengths and it is light in weight, making handling and laying relatively easy; if properly laid it produces an impervious, leak-free conduit.

Plastic pipe is, by definition, a flexible material. This is both an advantage and a disadvantage. Because it is a flexible material it can be used in conditions where rigid pipe would be difficult to work with, and it will absorb bending and impact stresses more readily than rigid pipe; because it is flexible the design criteria for rigid pipe do not apply and the in-use behaviour becomes less predictable. Plastic pipe does not fail catastrophically when improperly used but generally fails by a gradual decrease in vertical dimension until the conduit becomes unservicable.

2.0 General

The use of under-ground conduits for the conveyance of waste-water has been practised for over 3000 years but not until 1910 was any definite effort made to provide a rational design for such structures, taking into account the structural effect of the surrounding earth. At that time, Anson Marston of the Engineering Experiment Station, Iowa State College, initiated studies which led to the now commonly used "Marston formulae" for calculating earth loads on buried pipe.

A colleague of Marston, M. G. Spangler, continued this work and in 1947 published a definitive paper (4) summarizing the state of the art to that time, including work on the supporting effect of surrounding earth on flexible conduits. At that time "flexible conduits" were limited to corrugated metal culverts and thin-walled steel pipe but the theory and computations apply equally well to plastic materials. In his report Spangler states: "The (flexible) pipe itself has relatively little inherent strength, and a large part of its capability of supporting vertical load must be derived from the passive pressures induced as the sides move outward against the soil." "The action of a flexible pipe under (vertical) loading is one of large deflection change unaccompanied by rupture of the pipe wall; and for this reason, the design of the flexible types of conduits should be based upon the deflection of the ring rather than upon stress in the side walls as in the case of the rigid types."

"Laboratory tests (3) have indicated that the elastic theory of flexure as applied to thin rings (1) is applicable to these flexible conduits...." "Therefore, if the loads and pressures acting on a flexible pipe are known or can be assumed confidently, the deflection of the pipe can be determined by this theory within the elastic limit of the pipe material."

The Spangler formula, as presented in his 1947 paper, for horizontal deflection of flexible pipe under vertical loading is:

$$\Delta = F_d \frac{F_k . W_c . r^3}{EI + 0.061 e r^4}$$

in which Δ = horizontal deflection (inches)

F_d = deflection lag factor

F_k = bedding constant

W_c = vertical load per unit length of pipe, (pounds per inch)

r = mean radius (inches)

E = modulus of elasticity, pipe material

I = moment of inertia per unit length of cross section of pipe wall (inches^4 per inch)

e = modulus of passive resistance of the enveloping soil (pounds per inch^2 per inch)

Values of F_k for various values of bedding angle are shown in Table I.

TABLE I *

Bedding Angle degrees	Bedding Const. F_k
0	0.110
15	0.108
22.5	0.105
30	0.102
45	0.096
60	0.090
90	0.083

* after Spangler (4)

In Spangler's formula the calculation of the horizontal deflection is straight forward with the exception of the determination of a value for <u>e</u>, the modulus of passive resistance of the enveloping soil. This is defined as the unit pressure developed as the side of a pipe moves outward a unit distance against the side fill. Obviously this parameter is dependent upon the particular soil characteristics and backfilling.

With the current increased interest in, and use of, plastic pipe, the design of flexible conduits has assumed major significance. Materials certification associations have adopted standards dealing with the use of plastic pipe as buried conduit but these standards have some inherent deficiencies.

The American Society for Testing and Materials (ASTM) specification D2412 (6) covers among other things "the determination of load-deflection characteristics and stiffness factor which are used for engineering design."

The pipe "stiffness factor" is calculated as"

$$SF = 0.149\ F.r^3/\Delta Y$$

in which

SF = stiffness factor (inches ^{2} .lb/in)

F = load (lb/lineal in)

r = mean radius (inches)

Δy = vertical deflection (inches)

The pipe "stiffness ($F/\Delta y$) is used in a modification of the Spangler equation:

$$X = D_1.K.W_c.r^3/(SF + 0.61\ E'r^3)$$

which reduced to:

$$X = D_1.K.W_c/\ ((0.149\ F/\Delta y) + (0.061\ E'))$$

in which:

x = horizontal deflection (inches)

K = bedding constant

W_c = vertical load per unit pipe length (lb/in)

r = radius of pipe (in)

$F/\Delta y$ = pipe stiffness (psi)

D_1 = deflection lag factor

E' = modulus of soil reaction (psi)

This is basically the Spangler equation and has the same deficiency:- the soil reaction modulus is not available.

The Canadian Standards Association (CSA) has published several specifications on plastic pipe but CSA Standard B182.1 - 1967 is of particular interest in this case. The Standard "covers plastic drain and sewer pipe and pipe fittings for use underground" in applications including "building sewers and building drains", and "sanitary sewers and storm sewers". The Standard does not specify required rigidity or pipe stiffness other than to state that pipe "shall possess sufficient rigidity". Dimensions and wall thickness are given which are applicable to pipe manufactured of PVC and RMS.

3.0 System Design

3.1 When the Research Branch initially entered into this investigation of plastic pipe behaviour it was envisaged that a program of physical testing (field and laboratory) would be initiated. In the course of collecting background data it was found that testing programs had been carried out throughout the world although some of the results have not yet been published. Thus it was decided that the Research Branch would not carry out any physical testing as part of this work but would use data collected by others where available and applicable.

3.2 Pipe-Soil Interaction

The ASTM formula:-

$$X = D_1.K.W_c./\ ((0.149\ F/\Delta y) + (0.061E'))$$

has been found to generally provide an accurate estimate of pipe deflection when the appropriate values of $F/\Delta y$ and E' are used.

From the above formula, it is evident that the resistance to pipe deformation under a vertical load is represented by:

$$0.149\ \ F/\Delta y + 0.061\ E'$$

For PVC manufactured under the present CSA specifications B182.1, 6-inch diameter pipe, (SDR = 36) has an $F/\Delta y$ value of approximately 40 lb/in / IN. at 5% deflection. Assuming a soil modulus of 200 psi, the resistance to deformation provided by the pipe is equal to 32.8% of the total resistance. As the soil modulus increases, the relative value of the pipe stiffness decreases so that for a soil modulus of 2000 (95% Proctor density), the pipe itself is providing only 4.8% of the total resistance.

It is thus evident that for a good backfill condition a light weight pipe would be suitable. However, the installation would have to be made with extreme care, including hand tamping, backfill material selection and controlled compaction. These would all imply a more than usual degree of care and therefore a light weight pipe cannot be recommended.

A decrease in vertical diameter, and a concomitant horizontal deflection, equal to 5% of the unstressed pipe diameter is acceptable as an allowable maximum deflection. Therefore the maximum value of X becomes 0.05D. A deflection lag factor of 1.5 appears to be conservative (2) and should be acceptable as a safety factor. The value of K, the bedding constant, is available from Spangler's work (Table 1) but in cases where installation is not closely supervised and controlled a value of K = 0.110 should be used. The modulus of soil reaction is still largely an unknown factor which can vary from zero to probably 2000, depending on backfill conditions. For uncontrolled installation in "normal soil" a value of 200 is conservative.

For design purposes the ASTM formula thus reduces to:

$$0.05D = (1.5 \times 0.110 \times Wc)/((0.149\,F/\Delta y) + (0.061E'))$$

For a 6-inch diameter PVC pipe ($F/\Delta y = 40$), buried in soil weighing 120 lbs/ft^3 and with a soil modulus of 200 psi, a 5% decrease in vertical diameter would occur at a burial depth of approximately 6½ feet.

If a value of $F/\Delta y = 100$ is assumed, with other conditions as in the above example, the permissable burial depth is increased to approximately 8¼ feet.

The allowable burial as calculated above is the maximum permissable under the worst conditions. The value obtained for an $F/\Delta y$ value of 100 is adequate under these conditions and it is therefore concluded that the minimum allowable pipe stiffness should be specified as $F/\Delta y = 100$ lbs/in/IN.

Testing carried out by others (2) has obtained values for E' of approximately 300, 1000, and 2000 psi for sand backfill compacted to 68%, 85% and 93% Proctor density respectively. The assumed value of 200 psi under worst conditions is thus justified.

The results of the above work (2) also exhibited close correlation with the theoretical calculations used herein.

The design criteria presented above are admittedly conservative and are designed to prevent pipe failure under adverse conditions. Upon presentation of adequate supporting data, the values used for pipe bedding and soil modulus may be modified to provide for burial depths in excess of those obtained under worst conditions, or for superimposed loading. However, in the absence of such data, conservative values will be used.

4.0 Impact Strength

The resistance of a given pipe to the external loading applied during its use is of prime importance in any design. It is also a prerequisite that the pipe be able to withstand any abuse to which it is subjected prior to and during installation. Plastic pipe generally exhibits superior impact resistance when warm but suffers a loss of such strength at cold temperatures, which are quite common in Canadian Winter installation.

CSA Standard B182.1-1967, Section 4.2.6., specifies the minimum impact requirements for pipe manufactured under this standard at 23°C and 0°C. The minimum impact is 15 foot-pounds for a 2-inch pipe at 0°C.

The draft of Standard B196 for plastic ducting specifies a minimum impact of resistance of 25 foot-pounds at 0°F (-17.8°C). Considering the weight of sewer pipe, and the usual depths at which it is laid, an impact stress of 50 foot-pounds appears justified as the maximum to which pipe would be subjected during a sewer installation where reasonable care is taken. The temperature of 0°F is not an unusual one in installation practice.

It is therefore concluded that CSA Standard B182.1 should be modified to provide for a minimum impact resistance of 50 foot-pounds at -20°C, using a weight having a face radius of 2 inches, for pipe manufactured in accordance with this standard.

5.0 Summary and Conclusions

On the basis of information presented in this report, it is concluded that:

1. The Ministry of the Environment should approve the use of plastic pipe for buried, gravity-flow sewer installations.
2. Plastic pipe for the above use should be designed using the modified Spangler equation for flexible pipe:

$$X = \frac{D_1 . K . W_c}{(0.149\ F/\Delta y) + 0.061E'}$$

3. Maximum allowable decrease in the vertical diameter should be 5% of the pipe diameter, using a deflection lag factor of 1.5.
4. Canadian Standards Association (CSA) Standard B182.1-1967 should be modified so that any given pipe constructed in conformity with it will have a constant "pipe stiffness" ($F/\Delta y$) throughout the size range covered. A minimum pipe stiffness ($F/\Delta y$) of 100 psi at 5% deflection is required.
5. In the absence of conclusive evidence of local conditions to the contrary, a bedding factor (K) of 0.110 and a modulus of soil reaction (E') of 200 psi should be used in the design of such conduits.
6. In any such installation the contractor should be required to pass a plug not less than 95% of the internal diameter of the pipe through the pipe, not sooner than 24 hours, or later than 72 hours, after the completion of backfilling. In the event that the plug is not able to pass through the pipe, the pipe would be replaced by the contractor at his expense.
7. CSA Standard B182.1 should be modified so that all pipe manufactured under that standard be capable of withstanding an impact of 50-foot pounds at a temperature of $-20^{o}C$ under standard test conditions.

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